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RESEARCH MEMORANDUM

DATA ON SPOILER-TYPE AILERONS

By John G. Lowry

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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By John G. Lowry

Interest in spoiler-type ailerons has been intensified recently mainly because they give high reversal speeds for the thin, flexible wings now being used. For the purpose of this paper the term "spoiler" will be applied to many different aileron configurations that obtain their effectiveness by reducing the lift on one wing. For the sake of completeness, a bibliography on spoiler-type controls is included; these papers are arranged according to date of publication.

Examination of spoiler data given in the bibliography indicates that spoilers can be designed to provide adequate effectiveness at subsonic, transonic, and supersonic speeds but at subsonic and transonic speeds plain spoilers do not, in general, provide linear variation of effectiveness with projection, particularly at the lower velocities. In addition, recent data on thin wings (6 percent thick or less) show that a region of ineffectiveness exists at high angles of attack. Using a slot through the wing behind the deflected spoiler (see refs. 1 to 5) alleviates the ineffectiveness associated with both low projections and high angles of attack.

Figure 1 illustrates the effect of the slot. On the left, the rolling-moment coefficient C_l is plotted against spoiler projection δ_s for a plain and a slotted spoiler on an unswept wing (unpublished data). For projections of less than 1 percent the plain spoiler is seen to be ineffective. If a slot is added behind the spoiler and, in this case, a deflector is added to the lower surface, the effectiveness is almost linear with projection and considerably greater than for the plain spoiler. The nonlinearity of control effectiveness of the plain spoiler can be masked to some extent by providing aileron-stick deflections that will rapidly deflect the spoiler near neutral. Although this nonlinear stick-aileron motion may provide satisfactory control for this condition, the control effectiveness will not be satisfactory at high angles of attack as shown by the right-hand portion of figure 1. Here C_l is plotted against angle of attack α for a spoiler on a 30° swept wing of aspect ratio 4 (unpublished data). The plain spoiler is ineffective above an angle of attack of about 13°. The addition of the slot and deflector increases the effectiveness at all angles of attack and provides control up to 24°. This ineffectiveness at high angles of attack results from flow separation at the wing leading edge and is almost independent of spoiler projection. It is, however, alleviated to some extent by decreases in the wing taper ratio and wing sweep, and by increases in the Reynolds number.

The use of leading-edge devices to delay leading-edge separation would be expected to improve the effectiveness of a spoiler aileron. Figure 2 shows the effect of one such device - a drooped leading edge and chord-extension - on the effectiveness of both a plain and slotted spoiler on a 6-percent-thick, 45° sweptback wing of aspect ratio 4 and taper ratio 0.3 (unpublished data). For both the plain spoiler and the spoiler-slot-deflector, where the deflector projection δ_d is three-fourths of the spoiler projection δ_s, the addition of the leading-edge modification improved the spoiler effectiveness, particularly at moderate angles of attack. These data indicate that modifications necessary from a longitudinal-stability point of view should be beneficial if they delay or eliminate the leading-edge separation.

Since the slots are desirable for almost all configurations and necessary in many cases at subsonic speeds, their effectiveness at supersonic speeds is of interest. Figure 3 shows the variation of rolling-moment coefficient with angle of attack for both a plain spoiler and a spoiler-slot-deflector on a swept and an unswept wing at a low supersonic speed, $M = 1.20$ (unpublished data). The addition of the slot and deflector increased the effectiveness of the plain spoiler at all angles of attack for both wings. Some preliminary results at a Mach number of 1.6 indicate the same trends as do these data at $M = 1.20$. Thus, the slots that are so desirable at subsonic speeds are also beneficial at supersonic speeds.

In order to realize the advantages of low twisting moment and resulting high reversal speed, the wing structure with the spoiler must be as stiff as with other types of ailerons. Fortunately, spoilers should be located well to the rear of the wing and, for most spoiler and spoiler-slot configurations, slots through the wing or breaks in the skin can be located behind the torque box and should not seriously reduce the torsional stiffness of the wing.

The next part of the discussion is concerned with the location of spoilers on wings of different plan forms. Figure 4 shows the most satisfactory location for spoiler ailerons on swept wings. The results of many investigations at subsonic, transonic, and supersonic speeds (refs. 5 to 21 and unpublished data) have indicated that for best effectiveness the spoilers should be located in the shaded area. The forward or chordwise limit has been established from two considerations: (1) ineffectiveness at low projections (since this ineffectiveness increases with distance from trailing edge) and (2) unacceptable lag at low speeds. For configurations that do not operate at low speeds (for example, supersonic missiles), the lag may not be a determining factor as it decreases with increases in speed. The chord positions referred to are shown schematically on the right of figure 4. The spoiler location is considered

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as the point of highest deflection. The spanwise limits y_i and y_o are a function of the wing sweep.

Figure 5 shows the effect of sweep on these spanwise limitations. On the left is a typical example of the variation of effectiveness with aileron span for ailerons starting at the wing tips. For the unswept wing (unpublished data), the inboard 25 percent of the span does not give any appreciable rolling moment and, for the 50° swept wing (ref. 18), the outboard 15 percent is ineffective. From several similar investigations at both subsonic and supersonic speeds, the approximate variation with sweep for the inboard end y_i and the outboard end y_o has been established as shown on the right in figure 5. This plot shows that, as the sweep of the wing is increased, the spoiler should be moved inboard for best effectiveness.

Figures 6 and 7 show the most satisfactory locations for spoilers on 60° delta wings. The only limitation, based on the available data (refs. 22 and 23 and unpublished data), is the forward location of the spoilers. This limitation is based on ineffectiveness at small angles of attack at subsonic speeds. Figure 7 gives a typical example of the effect of chordwise location. The effectiveness C_l is plotted against projection at $M = 0.85$ for spoilers located at 60 percent root chord in the unsatisfactory region and at 93 percent root chord in the satisfactory region on a delta wing at zero angle of attack. It can be seen that the forward location is ineffective in producing rolling moment up to about 10 percent projection. The rearward location gives effectiveness throughout the deflection range. As the angle of attack is increased the forward spoiler tends to become more effective and has substantially the effectiveness of the rearward spoiler at 12° angle of attack.

A further restriction is necessary if the delta wing is equipped with a double slotted flap (ref. 23). In this case, the spoiler should be located on the flap (fig. 6). The right-hand portion of figure 7 shows the rolling-moment coefficient plotted against spoiler projection for a spoiler located ahead of the flap - the position found to be most satisfactory for relatively thick straight and swept wings - and for a spoiler located on the flap. It is obvious that when the spoiler is located ahead of the flap there is an undesirable variation of effectiveness with projection while the spoiler located on the flap provides sufficient control and has an almost linear variation with projection.

Now that the desirable location for spoilers on wings has been established to some extent, the next problem is to determine how big the spoilers have to be. At subsonic and transonic speeds experimental results must be relied on almost entirely. The results of configurations close to the desired one can then be adjusted to the desired configuration by using standard aileron design methods (refs. 24 to 26). The

effect of any changes in spoiler configuration must be obtained from existing experimental data. In general, flap-type spoilers will have about 10 percent less effectiveness than spoilers projected normal to the wing surface. An analysis of existing data has indicated that to provide adequate control spoilers should have a span of from 50 to 70 percent of the wing semispan and a projection of 7 to 10 percent of the mean chord. At supersonic speeds some helpful information is available concerning spoilers projected normal to the surface. Using a shock-expansion-separation theory the pressures ahead of the spoilers can be estimated and with the aid of empirical relationships the pressures behind the spoiler can be obtained (refs. 20 and 27). Thus for plain spoilers at supersonic speeds the effectiveness may be estimated with some degree of accuracy.

In the design of any control system it is necessary to know the operating forces of the control. The hinge-moment results for spoilers are not nearly so extensive at high speeds as are effectiveness data. The few data available do, however, show the general trends that are to be expected. Figure 8 shows the hinge-moment characteristics of flap-type spoilers on a 60° delta wing. The results (unpublished data) are presented as the variation of hinge-moment coefficient C_h with rolling-moment coefficient C_l, so that a comparison with a flap-type aileron of about the same size can be made. It can be seen that the hinge moments for this type of spoiler are of about the same magnitude as those of the flap at both subsonic and transonic speeds. At the subsonic speed, $M = 0.62$, a nonlinearity is present at low projections for the spoiler-type control - a phenomenon typical of this type of control (ref. 5).

When a spoiler-slot-deflector arrangement is used, the hinge moments of the deflector would be expected to reduce the hinge moments of the spoiler since the deflector should be unstable and tend to open because of its rear hinge location. Figure 9 shows the results of a recent investigation (unpublished) of a spoiler-slot-deflector on a 6-percent-thick 35° swept wing at $M = 0.85$. The hinge-moment coefficient C_h is plotted against spoiler projection δ_s for a plain flap-type spoiler and for a spoiler-slot-deflector when the deflector projection δ_d is one-half the spoiler projection. The deflector appreciably reduces the hinge moments of the spoiler particularly in the spoiler-deflection range from 1 to 4 percent chord. The curves are not faired from 0 to 1 percent projection since no data are available and reversals similar to those shown in figure 8 might be expected. Variation of the ratio δ_s/δ_d will allow one means of adjusting the hinge moments of this type of control and appears to offer promise of a control of good effectiveness and reasonably low hinge moments.

As would be expected, the hinge moments of thin-plate or circular-arc spoilers are small compared to those of flap-type spoilers since the hinge moments can be developed only on the top and bottom edges of the spoiler. Results at low speeds on relatively thick wings (refs. 5 and 28) and on a swept wing at transonic speeds (ref. 29) confirm the low hinge moments but show that they are very nonlinear. This nonlinearity can probably be tolerated since they give forces about one-thirtieth as large as do flap-type ailerons on a typical fighter at transonic speeds.

These low hinge moments are all very well, provided that the necessary 10 percent projection can be incorporated in a 4-percent-thick wing. Figure 10 shows two ways of doing this along with a typical flap-type spoiler. The top sketch is the flap-type spoiler where the projection is limited only by the chord of the flap and the deflection. The center sketch shows a form of circular-arc spoiler (ref. 30). In this case three circular-arc spoilers, one behind the other, are linked so that the rear spoiler deflects 3 times as fast as the front spoiler and at full deflection provides a solid spoiler of the desired height. The bottom sketch is the so-called semaphore spoiler and consists of several flat plates hinged in the chord plane and deflected similar to semaphore train signals. At full deflection, they can form an almost solid spoiler of considerable deflection as shown in the figure. The number and length of the individual arms will depend on the deflection desired and the wing thickness. These last two types can be made to have relatively low hinge moments while still providing the desired projection.

Another means of providing spoiler control with low operating forces is that of using a jet of air to replace the spoiler (refs. 31 to 33). Figure 11 shows some preliminary results of a jet control utilizing stagnation pressure on a 35° swept wing. For these tests a very short span spoiler was used but the variation of effectiveness with span should be the same as for a conventional spoiler. With stagnation-pressure air, the jet is as effective as a 3-percent-chord spoiler and does not show the loss in effectiveness at large angles of attack. This, of course, is not sufficient for a fighter-type airplane but could be used as emergency control if normal control were obtained by using air at high pressure where roll is obtained both from jet thrust and from changing circulation around the wing. In order to vary the rolling effectiveness C_l, the slot width can be varied. The right-hand portion of figure 11 shows the variation of C_l with gap width δ_g; an almost linear variation is indicated for the jet alone. One means of increasing the effectiveness is to deflect a spoiler ahead of the jet. The curve for this configuration shows that considerably more effectiveness is obtained. In this case, the total spoiler projection, 3 percent chord, could be fitted as a simple circular-arc spoiler within the wing.

In addition to the effectiveness and hinge moments of a control system, its effect on the rest of the airplane is of importance. Any obstruction such as a spoiler that causes separation of flow behind it will create turbulent flow over parts of the airplane. This turbulent flow may result in buffeting or shaking of the airplane. The few data that are available (unpublished) on flow fluctuations behind a spoiler are too sketchy to provide any reliable indication of either the magnitude or frequency of the air flow. A survey of the airplanes using spoilers at high subsonic speeds indicates, however, that about one-half of them have had no trouble from buffeting. Although not much can be done as far as predicting buffeting, it is known that perforating the face of the spoiler or otherwise breaking up the solid blocking will reduce any tendency of buffeting but that this will also cause some reduction in effectiveness, the magnitude of the reduction depending on the amount of area removed.

Another point of concern in the use of spoiler-type ailerons is the drag penalty associated with their use. Figure 12 shows the drag coefficient due to control deflection ΔC_D for both flap-type ailerons and spoiler ailerons that produce the same rolling-moment coefficient. The left-hand portion is for a swept wing at subsonic speeds (unpublished data) and the right-hand portion is for an unswept wing at supersonic velocities (refs. 15 and 34). It can be seen that there is a large drag associated with spoilers at low angles of attack but that the drag increment decreases rapidly with increased angle of attack and at angles of attack of about 8° the spoiler and aileron produce the same drag. In order to give some idea of the seriousness of these relatively high drags associated with spoilers at low angles of attack, calculations were made for a modern fighter making a 90° bank in 1 second at 30,000 feet and at a Mach number of 0.85. These calculations show that the speed of the airplane will be decreased only 2 miles per hour. If the maneuver is assumed to be an entry into a turn, even less loss in speed would be obtained since the angle of attack increases during the maneuver.

In conclusion, in general, there should be a slot through the wing behind the deflected spoiler. The spoiler should be located to the rear of the wing in the center portion of the wing semispan. Satisfactory spoiler configurations can be designed that will have reasonably low operating forces.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 4, 1953

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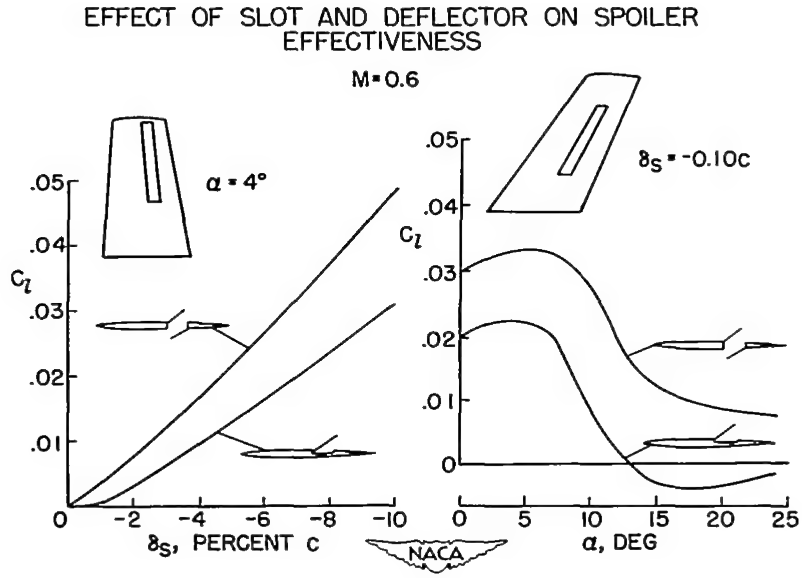

Figure 1

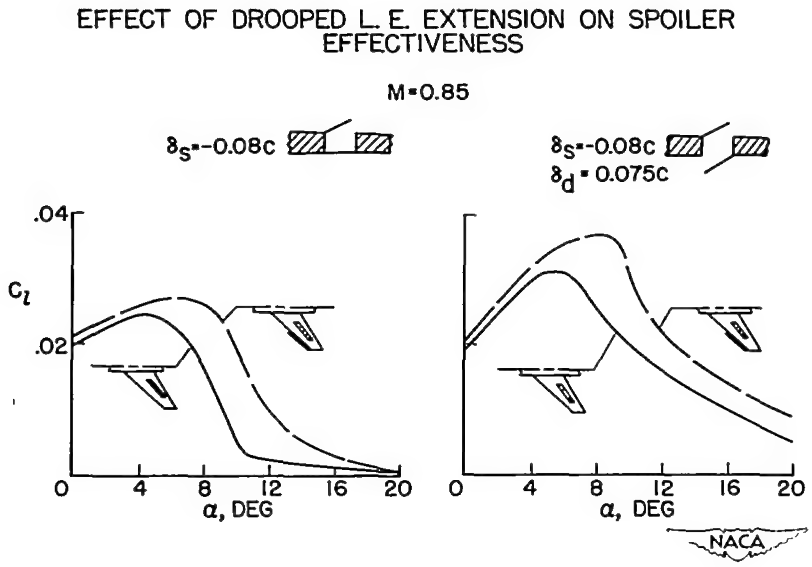

Figure 2

EFFECT OF SLOT AT LOW SUPERSONIC SPEEDS

M=1.20

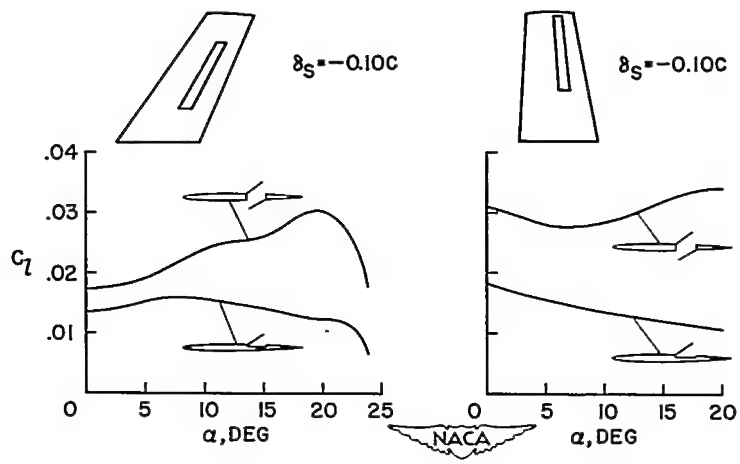

Figure 3

SATISFACTORY SPOILER LOCATION ON SWEPT WINGS

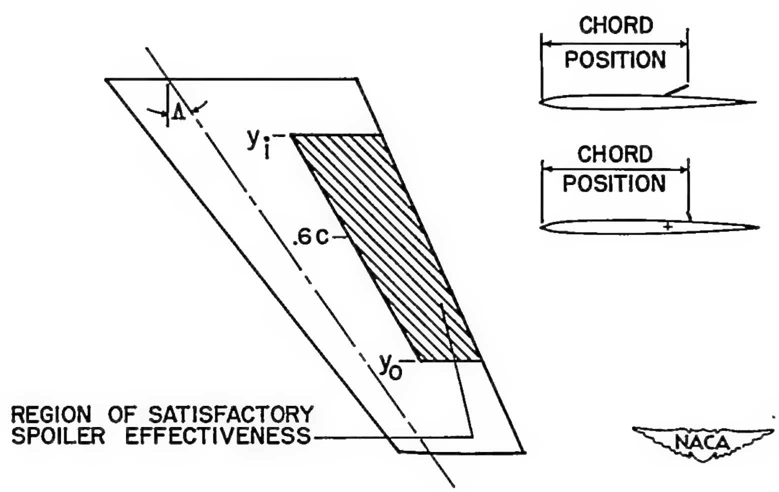

Figure 4

EFFECT OF SPANWISE SPOILER LOCATION
ON SWEPT WINGS

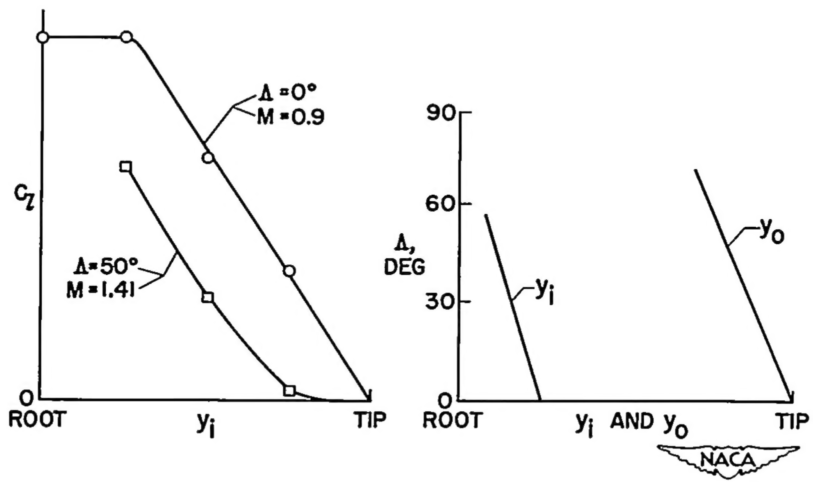

Figure 5

SPOILER LOCATION ON 60° DELTA WING

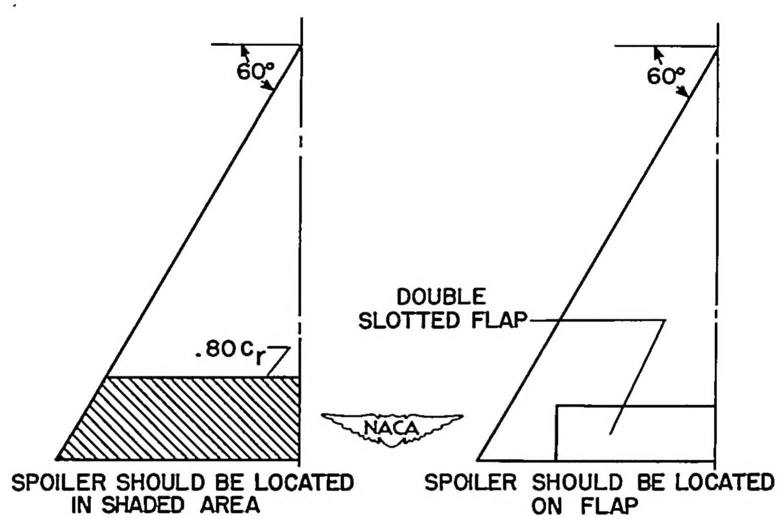

Figure 6

EFFECT OF CHORDWISE LOCATION OF SPOILERS ON 60° DELTA WING

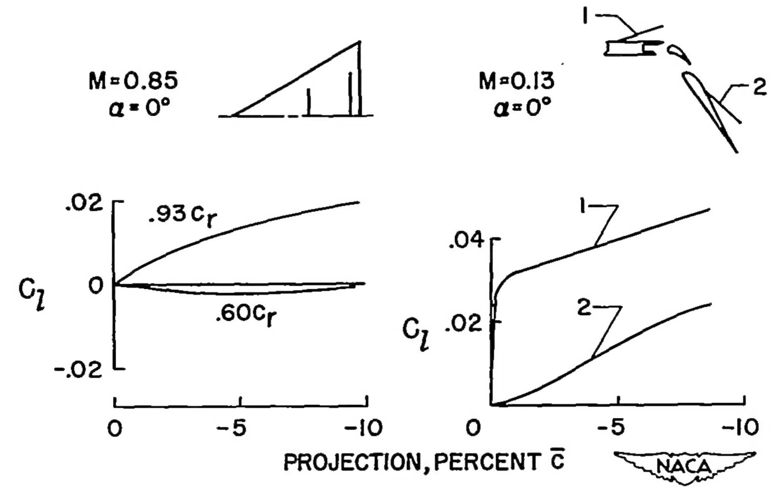

Figure 7

HINGE MOMENTS OF SPOILER AILERONS
60° DELTA WING

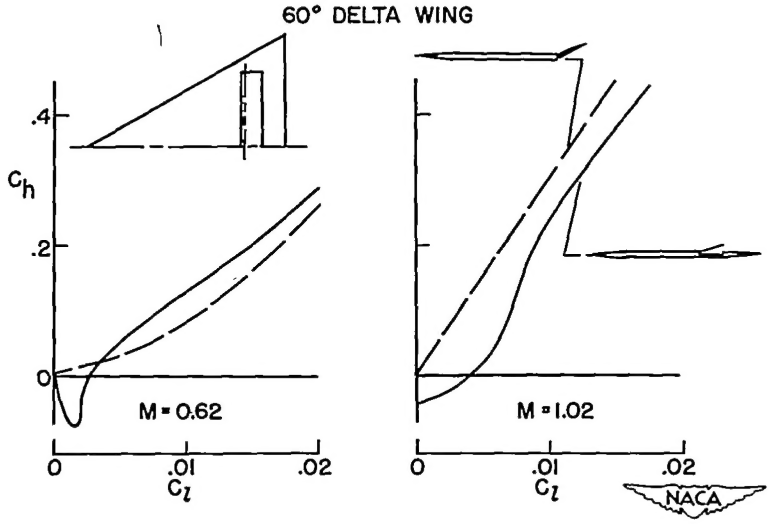

Figure 8

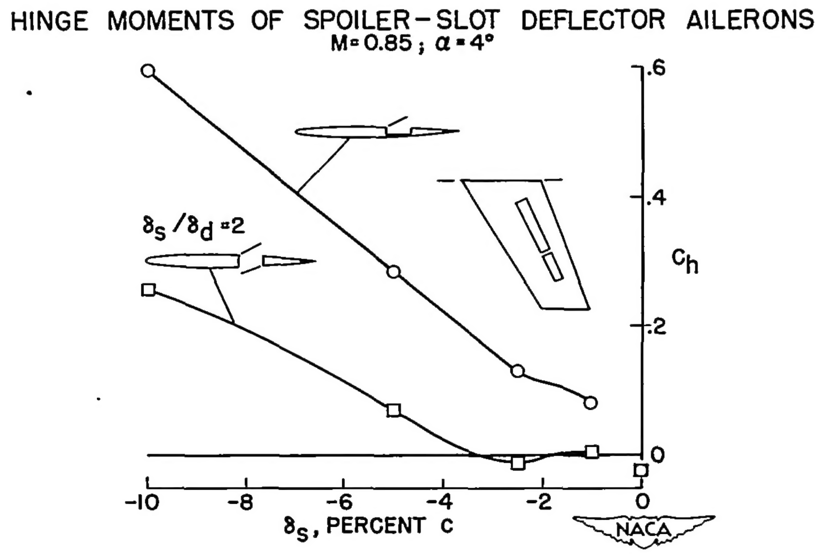

Figure 9

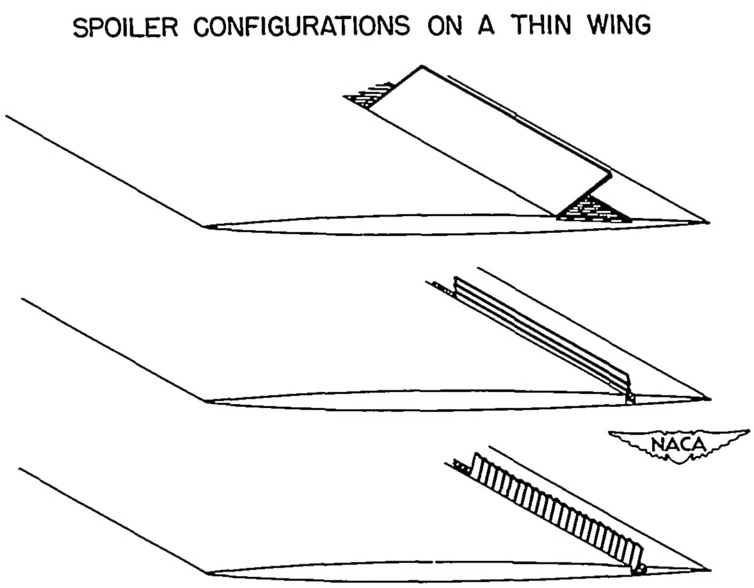

Figure 10

JET CONTROL UTILIZING AIR AT STAGNATION PRESSURE

M = 0.28

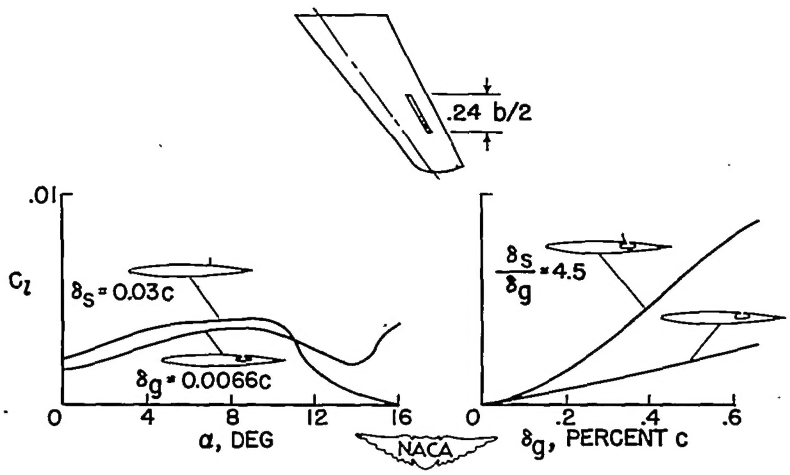

Figure 11

COMPARISON OF DRAG CHARACTERISTICS OF FLAPS AND SPOILERS

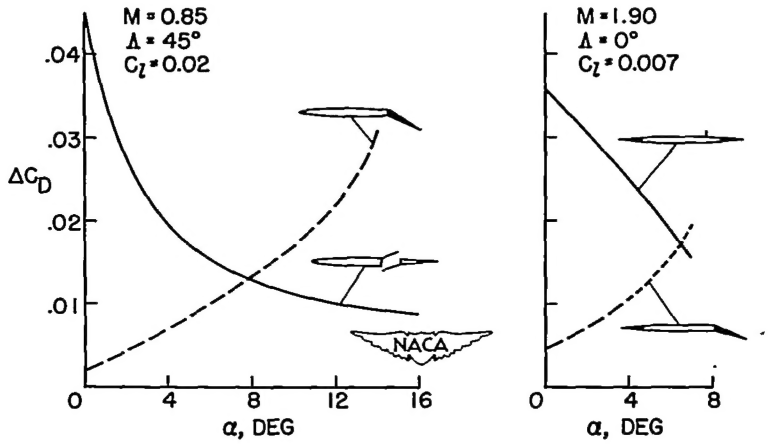

Figure 12

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